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SODIUM VAPOR EXPERIMENT

Quarterly Progress Report No. 7

Covering the Period

1 January - 31 March 1967

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I. INTRODUCTION

The purpose of this contract is to investigate the dynamics of the upper atmosphere through analysis of the motion of sodium vapor trails ejected from sounding rockets. Data are taken photographically from several widely separated sites. Triangulation is used to determine winds from the rate of motion of the trail, and densitometry measurements determine the growth rate and small-scale structure of the trail. Complete descriptions of the experimental and analytical methods are given in reports covering NASA contracts NAS5-215 and NAS2-396. Theoretical studies of the dynamics of the upper atmosphere are directed toward formulation of models based on the observations. The first series of rocket firings occurred during November 1964 from Wallops Island and simultaneously from a ship at selected distances from Wallops Island. The objective of the series was to investigate the variation of the vertical wind structure at two places separated by different distances.

The results of the first series were seriously limited by vaporizer malfunction, but one set of trails separated by 180 km showed the winds to differ significantly above 120 km. Previous analysis of several up and down trails separated by a distance of about 50 km have shown no wind variations over that distance. Continuation of the study of horizontal variation of the vertical wind profile was an objective of a series of flights from Wallops Island during June 1965. Two vapor trails were ejected from rockets fired nearly simultaneously on different azimuths during the evening twilight of 22 June and the morning of 23 June. A fifth rocket ejected a trail of TMA at 2300 EST on 22 June to allow observations of the time variations of the winds.

The spatial separation of the simultaneous trails in June was not large and the differences in the wind profiles were small. The evening trails were separated by only 25 km, and the wind speed around 100 km was only about 30 m/sec. The trail separation and wind speed of the morning trails were greater than those of the evening trails. The TMA trail, because of poor rocket performance, did not reach the predicted altitude and faded very quickly, causing some loss of data in the 100 to 125 km region and reduced the accuracy of the data below that height. Thus, the information on spatial variations is limited. Much more information was obtained from the time-space trails. The low wind speeds during evening twilight had increased by a factor of 2 to 3 by 2300 EST (about 3 hours later) and the familiar spiral pattern had begun to form. The clockwise spiral was even more apparent over much of the height region by morning twilight and the whole pattern had been continually rotated through the night, as has been previously observed in other time sequences in January and July 1964. The observations should be more closely spaced in order that the exact nature of the changes may be determined. Such closely spaced observations were the purpose of the series of firings at Wallops Island in January 1966.

During the night of 17-18 January 1966, five vapor trail payloads were successfully launched from Wallops Island. This series showed that observations spaced an hour or two apart provide much information concerning the manner in which the winds vary. Some of the initial observations were discussed in the Quarterly Report covering the period 1 January 1966 - 31 March 1966. It was shown that the large scale spiral pattern collapsed into an irregular low speed pattern in about 6 hours and that the entire pattern moved slowly downward.

Five vapor trail payloads were successfully launched from Wallops Island during the night of 16-17 July 1966. The results were discussed in the previous quarterly progress report. Again it appears that part of a large scale cyclic pattern was observed during the 8-hour period during which the firings occurred. The downward motion of the entire profile which was observed in the January 1966 series of vapor trails was present throughout the July series also.

During the period covered by this report, six vapor trail rockets were launched at Ft. Churchill and preliminary data reduction from five of the trails has been completed. This data is presented in this report along with a preliminary discussion of the winds and trail structure.

Section V of this report is a summary of a paper which discusses the vapor trail measurements made at Wallops Island over the past few years. The paper has been submitted to the Journal of Geophysical Research for publication.

II. ROCKET FIRINGS

During the night of 31 January - 1 February 1967 a series of six vapor trail payloads were fired on Nike Apache rockets from Ft. Churchill, Canada. Each of the vapor trails was ejected within a few minutes of the firing of another Nike-Apache carrying a pitot static tube payload. It was anticipated that a good comparison of data from the two techniques would be obtained. Except for rocket malfunction on 14.316 it appears that good data were obtained. The times of the rocket launchings are given in Table I. All firings of vapor trail payloads occurred three minutes after the pitot tube firings except for 14.314 which was fired about 40 minutes earlier than scheduled because cloud cover was rapidly increasing over the camera sites.

Camera sites were located at the main base, Twin Lakes, Belcher, Seal River, and Caribou River. All sites had automatic 70 mm cameras and modified K-24 aerial cameras which could be hand operated in case of power failure.

Clouds were present at Belcher during the evening twilight firing and at Seal River and Caribou River during the last firing. Aurora was present throughout the night and was particularly bright around midnight. It was very cold (below -40°). However camera operation was good. In most cases the heaters were adequate and camera failure was minimal.

III. WIND DATA

Hodographs of the winds obtained from NASA 14.311, 14.312, 14.313, 14.323, and 14.324 are given in Figures 1-5. One of the outstanding features of the profiles is the high wind speeds above 120 km prior to midnight. The speed at 130 km increased from 200 m/sec at 1912 CST to about 300 m/sec at 2149 CST. By 2341 CST the speed had begun to decrease and by 0229 was below 75 m/sec. Later at 0524, the speed over partof the region was increasing again. The time required for the high wind to decrease to a minimum value and to start to increase again is 5 to 7 hours. This time is comparable to that observed for similar changes at Wallops Island. However, wind speeds of 300 m/sec have never been observed at Wallops Island.

The winds below 120 km also show some interesting changes with time. The direction of the entire pattern slowly rotates from the Southwest to South to West and finally to Northwest at the time of the last measurement of the series. The total rotation is about 270° in a little over 10 hours. This is very nearly the rotation expected from the Coriolis parameter. At 1912 CST the wind below 120 km forms a relatively small overlapping pattern with five sharp bends which occur at 99, 102, 107, 110 and 115 km. Two and one half hours later at 2149 CST, the wind speed has increased and the overlapping pattern has begun to spread out, but the bends although less sharp are still readily apparent. After another two hours at 2341 CST, the speed has increased still more and the pattern is much more spread out, but the bends are still present. Similar bends occur at some of the same heights at much later times (0229 and 0524 CST), but the relation to the earlier pattern is not certain. At these later times, the overlapping spiral patterns have again formed as the winds in the upper region decreased. An unusual feature in the profile at 0524 CST are the sharp bends occurring at 120 and 124 km. Such sharp corners are often observed at lower altitudes but seldom at these heights. The bends and joining segments of the hodograph from NASA 14.314 at 0524 CST are easily identified with the features on the vapor trail shown in Figures 6 and 7. Similar features of wind patterns have also been observed to persist for several hours during the night at Wallops Island.

IV. VAPOR TRAIL IRREGULARITIES

The small scale irregular structure that usually appears in vapor trails has often been discussed in previous reports on the contract. Some investigators consider some of the trail phenomena as directly observable evidence of turbulence in the ambient atmosphere. It has been emphasized in a report on this contract that such a conclusion is not completely obvious as is often claimed and may even be incorrect, since the ejection mechanisms and vehicle action causes varied types of trail distortion. Figures 6 and 7 are good examples of such distortion produced during the ejection of the trail. The striations in the lower trail correspond to those expected from a canister with a single orifice spinning at 7 r. p. m.. Figures 6 & 7 were made 90 secs. apart and clearly show the persistence of the small scale features as the trail expands. It is evident that such structure would complicate the analysis of early time trail growth. The diffusive growth of such a trail in a wind shear was discussed in Quarterly Progress Report No. 6, Feb. 1967. It appears that molecular diffusion governs the expansion of the trail shown in Figures 6 and 7 and there is no evidence of a requirement for mixing or expansion through turbulence. The upper limit of the irregular structure on this trail was at 104 km. The trail from 14.323 also showed structure at 104 km. The trails from 14.311 and 14.313 had irregular structure up to 108 km but 14.312 was smooth above 100 km. Trails at Wallops Island have much the same characteristics. They usually become smooth somewhere between 100 and 110 km and this height varies from trail to trail.

The altitude over which winds are obtained from a night trail is limited by the efficiency of the chemiluminescent process at both high and low altitudes. At Wallops Island winds can usually be obtained between 95 and 135 km. At Fort Churchill the upper limit is about 130 km, but most of the trails extend below 95 km, maybe as low as 90 km in some instances. The luminous process is thought to involve atomic oxygen. This observation may then be interpreted as evidence that the entire atomic oxygen profile is 3 to 5 km lower at Ft. Churchill than at Wallops Island.

V. SUMMARY OF WIND ANALYSIS

A paper entitled "Upper-Atmospheric Winds and Their Interpretation" by J. F. Bedinger, H. Knaflich, E. Manring and David Layzer was submitted to the Journal of Geophysical Research for publication. The following is a summary of the analysis and conclusion presented in this paper.

This paper discusses a homogeneous collection of observational material comprising thirty horizontal-wind profiles, derived from photographs of artificial vapor trails ejected by rockets over Wallops Island, Virginia (38°N) between 1959 and 1964. The observations extend over the height range 65-225 km and are essentially complete in the range 80-140 km, on which the present discussion concentrates. They have a height resolution of about 0.1 km at 100 km and about 1 km at 130 km.

The present data are analyzed in the light of results previously obtained from radar observations of ionized meteor trails between 80 and 105 km by Greenhow and Neufeld at Jodrell Bank (53°N) and by Roper and Elford at Adelaide (35°S). The following observational conclusions are reached: --

1. The temporal variation of the horizontal wind at any fixed level in the region under consideration has a continuous power spectrum of variable form with rather broad peaks at 12 and 24 hours, most of the energy lying outside these peaks. 2. The power spectrum of the large scale component of the horizontal wind, derived by smoothing over a height interval of 25 km, contains comparatively little energy at periods less than 12 hours. 3. The horizontal-wind vector shows a strong tendency toward clockwise rotation with increasing height. This is true not only of the smoothed wind profile but of the residual wind profile as well. Indeed, the tendency toward clockwise rotation is even more marked in the residual profile than in the smoothed profile. 4. There is some evidence that the phase of the horizontal-wind profile propagates downward at a nonuniform rate, preserving small-scale features of the profile. 5. The structure of the horizontal-wind profiles between 80 and 130 km is markedly stratified. Changes of the vertical gradient of the horizontal wind are usually concentrated in narrow

layers, sometimes less than 0.1 km thick. Between these layers the vertical gradient of the horizontal wind usually changes slowly in magnitude and direction. This tendency towards stratification gives the horizontal-wind hodographs their characteristic appearance: a typical hodograph consists of straight or slightly curved sections, along which equal-height markers are distributed at roughly equal intervals, joined at sharp corners. 6. The mean amplitude of the wind is strongly correlated with the structure of the horizontal-wind profile. Regular spiral profiles are associated with exceptionally large mean winds, irregular profiles with small mean winds. The kinetic-energy density profile of a typical large-amplitude spiral has a single well-defined peak between 100 and 110 km, while that of an irregular profile has a series of narrow peaks whose amplitude diminishes with height. 7. The kinetic-energy density profile averaged over a large number of profiles appears to have the same shape for large-amplitude and small amplitude wind systems. The logarithmic decrement of the quantity ρV_h^2 is approximately constant below 120 km, decreases in magnitude between 120 and 130 km, and is again roughly constant above 130 km, where it is appreciably smaller than it was below 120 km.

Of these conclusions, the first four (apart from the statement concerning the polarization of the residual wind) were prefigured by the radar observations, and in particular by the work of Greenhow and Neufeld. The last three conclusions appear to be substantially new.

We suggest as a tentative basis for interpreting the observations three main assumptions: --

A. Upper-atmosphere winds are driven primarily by forces resulting from the absorption of thermal and tidal energy of solar origin in the lower atmosphere.

B. Upper-atmosphere winds represent predominately gravitational (gravitational-compressional) oscillations.

C. These oscillations are strongly nonlinear. These assumptions have certain features in common with assumptions underlying previous attempts to interpret upper-atmosphere winds. For example, assumption B underlies the gravity-wave hypothesis of Hines and assumption C the turbulence hypothesis of Greenhow and Neufeld, Roper and Elford, Blamont, and others. However, it is argued in this paper that both the gravity-wave hypothesis and the turbulence hypothesis, as they are commonly understood, are untenable on observational and theoretical grounds. The gravity-wave hypothesis, which attributes the non-periodic component of the wind system to a superposition of independently propagating internal gravity waves, possibly generated by irregular wind systems and instabilities in the lower and middle atmosphere, appears to be ruled out by observational evidence showing that the Fourier components into which the horizontal-wind profile may be decomposed do not propagate independently. The turbulence hypothesis appears to be inconsistent with inferences based on observations of turbulent shear flows in the laboratory and with Richardson's criterion as formulated by Townsend and by Layzer. The present discussion shows that the strong nonlinearity of upper-atmosphere oscillations provides the key to an interpretation of several of their most conspicuous properties, including the form of the power spectrum at a fixed level and the phenomenon of stratification.

The paper concludes with an enumeration of further experiments needed to improve our understanding of the dynamics of the upper atmosphere.

VI. FUTURE PLANS

Reduction and analysis of the data from the Ft. Churchill series will continue. Analysis will be directed toward the temporal variations of the winds as observed from the sequential vapor trails at Churchill and Wallops Island.

Construction of payloads for future firings will begin.

TABLE I

ROCKET NUMBER	PAYLOAD TYPE	FIRING TIME C.S.T.
14.315	P.T.	1717 31 Jan.
14.310	Na-Li	1720
14.316	P.T.	1909
14.311	TMA	1912
14.317	P.T.	2146
14.312	TMA	2149
14.318	P.T.	2338
14.313	TMA	2341
14.319	P.T.	0226 1 Feb.
14.323	TMA	0229
14.314	TMA	0524
14.322	P.T.	0558

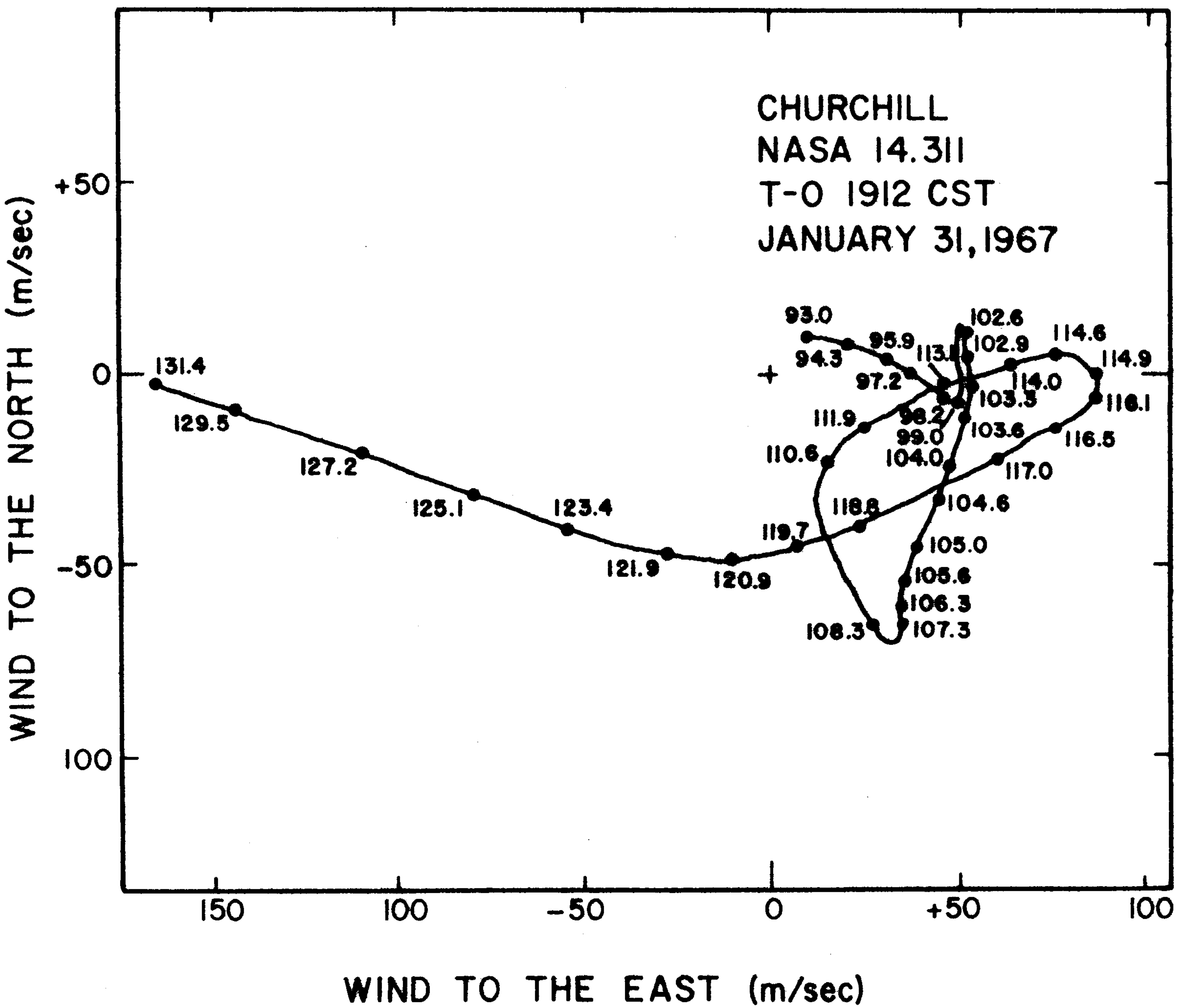
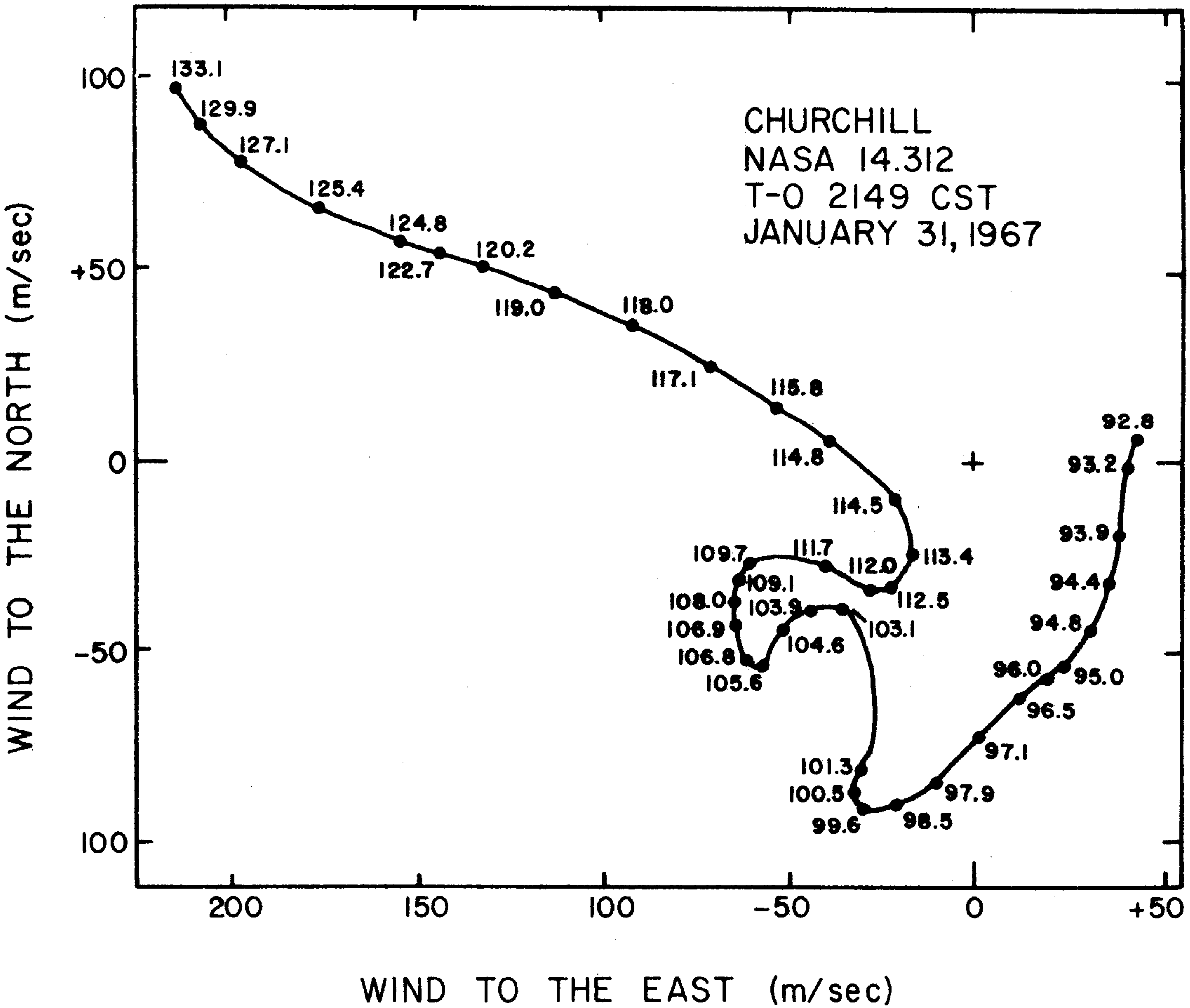

CHURCHILL
NASA 14.311
T-0 1912 CST
JANUARY 31, 1967
WIND TO THE NORTH (m/sec)
WIND TO THE EAST (m/sec)
+50
0
-50
100
150
100
-50
0
+50
100
93.0
94.3
95.9
97.2
98.2
99.0
102.6
102.9
103.3
103.6
104.0
104.6
105.0
105.6
106.3
107.3
108.3
110.6
111.9
113.1
114.0
114.6
114.9
116.1
116.5
117.0
118.8
119.7
120.9
121.9
123.4
125.1
127.2
129.5
131.4

Figure 1



CHURCHILL
NASA 14.312
T-0 2149 CST
JANUARY 31, 1967
WIND TO THE NORTH (m/sec)
WIND TO THE EAST (m/sec)
100
+50
0
-50
100
200
150
100
-50
0
+50
133.1
129.9
127.1
125.4
124.8
122.7
120.2
119.0
118.0
117.1
115.8
114.8
114.5
113.4
112.0
112.5
111.7
109.7
109.1
108.0
106.9
106.8
105.6
104.6
103.9
103.1
101.3
100.5
99.6
98.5
97.9
97.1
96.5
96.0
95.0
94.8
94.4
93.9
93.2
92.8

Figure 2

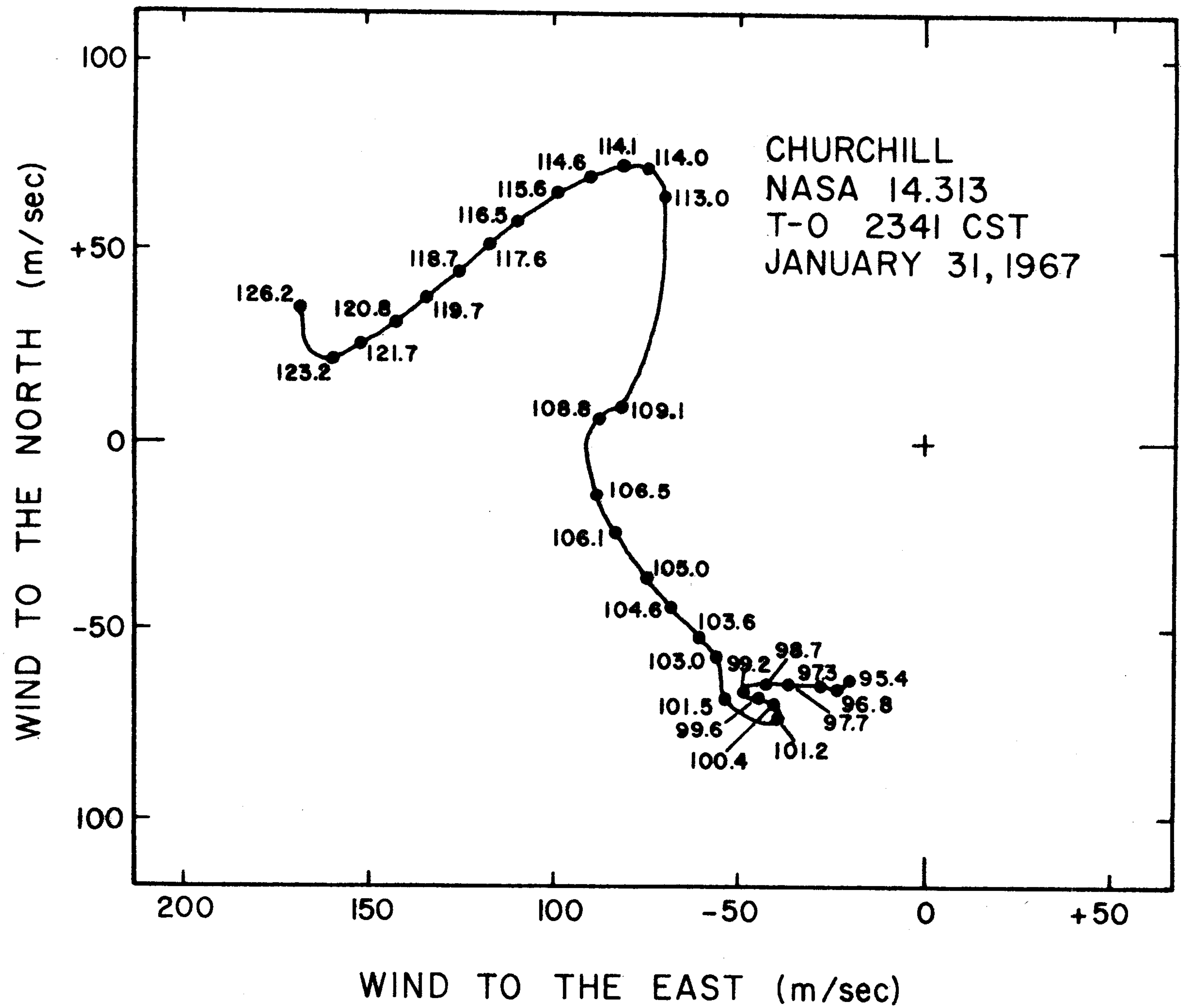

CHURCHILL
NASA 14.313
T-0 2341 CST
JANUARY 31, 1967
126.2
123.2
121.7
120.8
119.7
118.7
117.6
116.5
115.6
114.6
114.1
114.0
113.0
109.1
108.8
106.5
106.1
105.0
104.6
103.6
103.0
99.2
98.7
973
95.4
96.8
97.7
101.5
99.6
100.4
101.2
100
+50
0
-50
100
200
150
100
-50
0
+50
WIND TO THE NORTH (m/sec)
WIND TO THE EAST (m/sec)

Figure 3

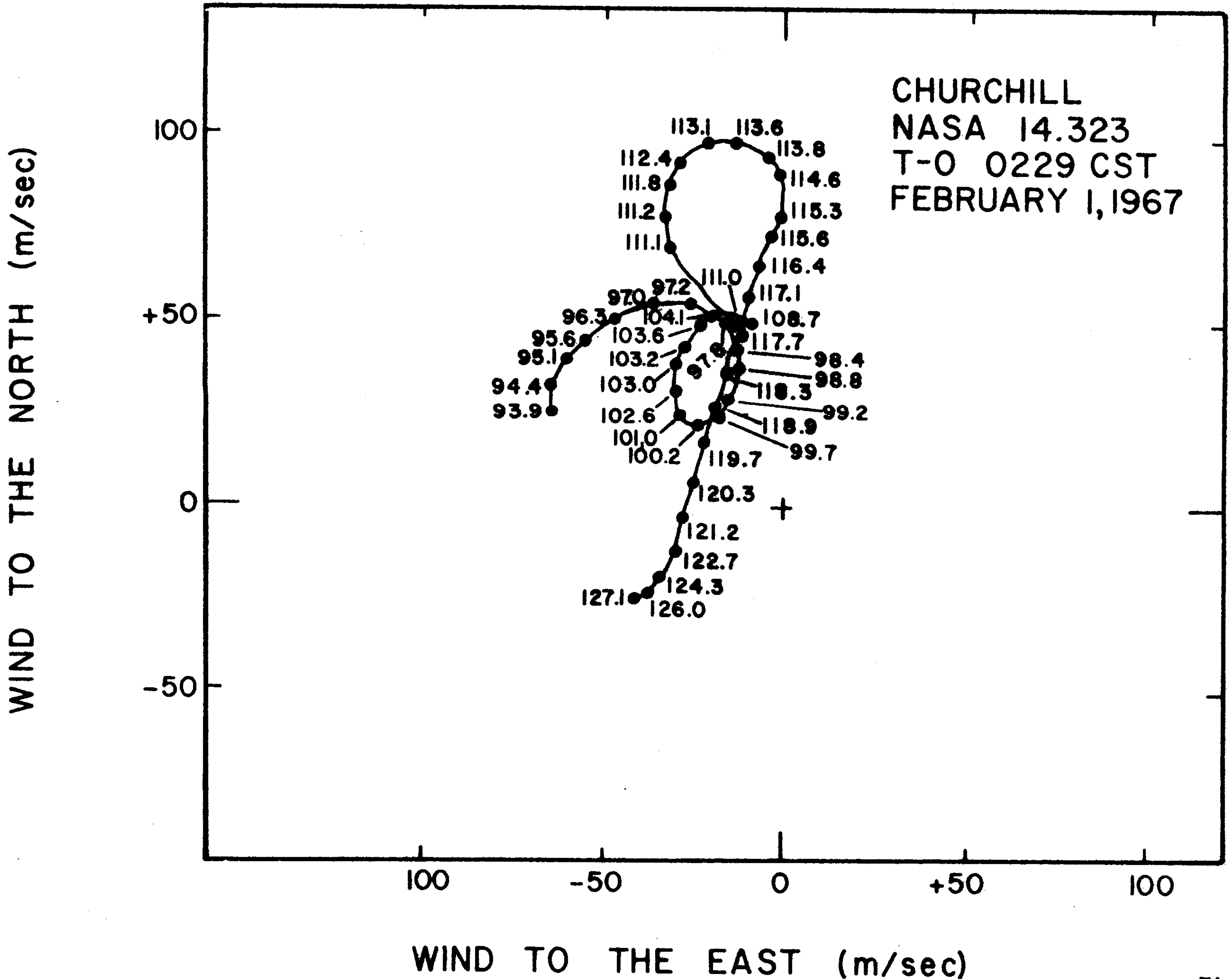

CHURCHILL
NASA 14.323
T-0 0229 CST
FEBRUARY 1, 1967
WIND TO THE NORTH (m/sec)
WIND TO THE EAST (m/sec)
100
+50
0
-50
100
-50
0
+50
100

Figure 4

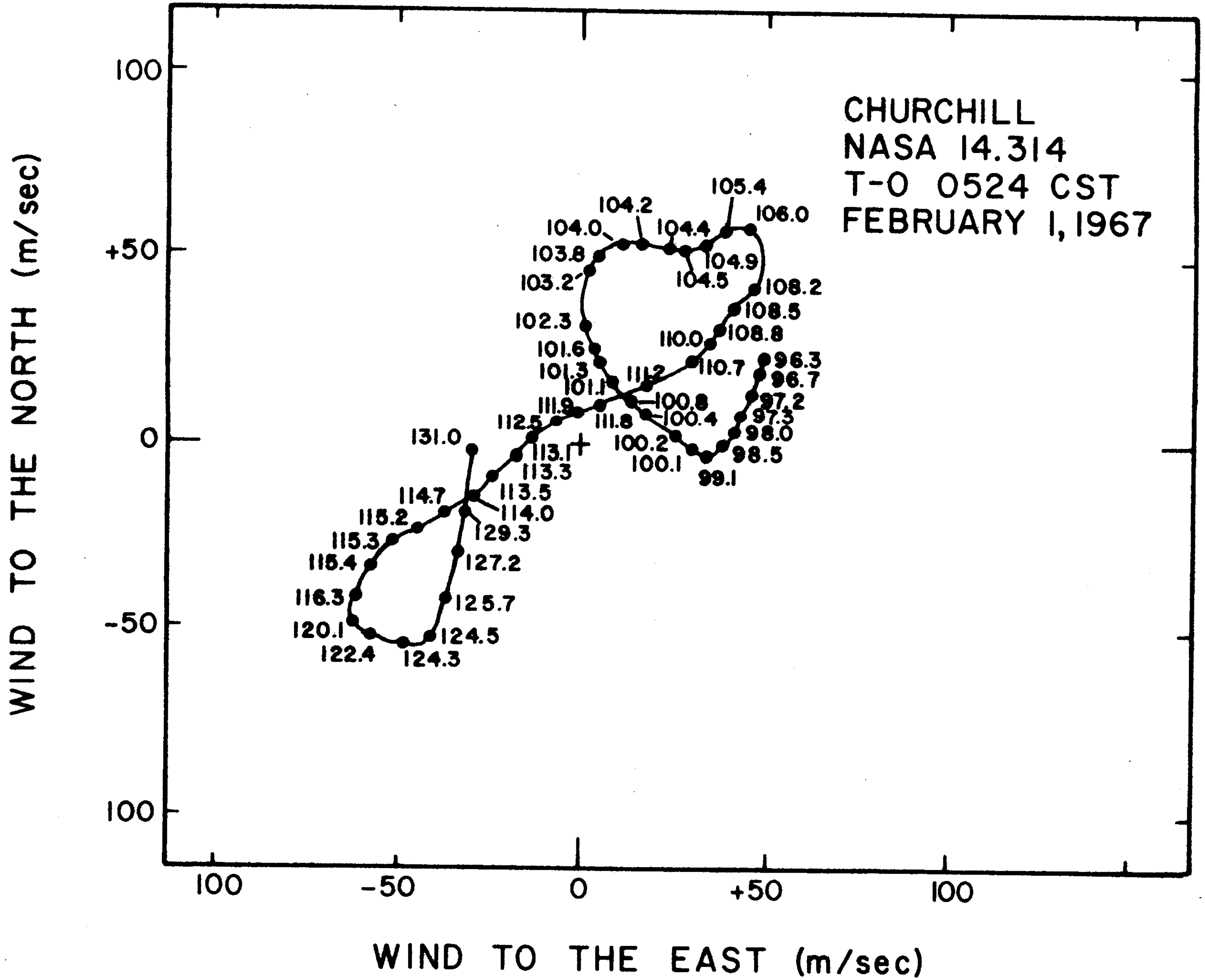

CHURCHILL
NASA 14.314
T-0 0524 CST
FEBRUARY 1, 1967
WIND TO THE NORTH (m/sec)
WIND TO THE EAST (m/sec)
100
+50
0
-50
100
100
-50
0
+50
100
96.3
96.7
97.2
97.3
98.0
98.5
99.1
100.1
100.2
100.4
100.8
101.1
101.3
101.6
102.3
103.2
103.8
104.0
104.2
104.4
104.5
104.9
105.4
106.0
108.2
108.5
108.8
110.0
110.7
111.2
111.8
111.9
112.5
113.1
113.3
113.5
114.0
114.7
115.2
115.3
115.4
116.3
120.1
122.4
124.3
124.5
125.7
127.2
129.3
131.0

Figure 5

Figure 6

Figure 7